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(54) METHOD FOR CONTROLLING HEAT GENERATION LOCALLY IN A HEAT-GENERATING PIPE UTILIZING SKIN EFFECT CURRENT

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ABSTRACT:

CLAIMS: Show all claims

*** Note: Data on abstracts and claims is shown in the official language in which it was submitted.

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ABSTRACT OF THE DISCLOSURE

In a heat-generating pipe comprising a ferromagnetic pipe and an insulated conductor line installed therethrough wherein an A.C. flows through concentratedly in the inner skin region thereof due to the skin effect of A.C., heat quantity generated in the heat generating pipe is locally controlled by changing one or more factors of those consisting of cross-sectional area of the conductor line, resistivity of the same, inside diameter of the ferromagnetic pipe, resistivity of the same and permeability of the same.

This invention relates to a method for controlling heat generation locally in a heat generating pipe. More particularly this invention relates to a method for controlling heat generation locally according to the demand of a to-be-heated body, in a heat generating pipe which utilizes skin effect current and comprises as a heat generating body, of a ferromagnetic pipe to which electricity is supplied from one source.

The heat generating pipes utilizing skin-effect current in which the method of the present invention is applied are those disclosed in U. S. Patent 3,293,407 or U. S. Patent No. 3,515,837.

The principle of heat-generating pipe utilizing skin effect current will be more fully described referring to two diagrams, Figures 1 and 2.

Figures 1 and 2 show the constructions and wirings of two heat-generating pipes based upon different principles; and Figure 3 is one embodiment of the present invention hereinafter fully explained.

Figure 1 is the construction and wiring of the heat-generating pipe disclosed in the above-mentioned U. S. Patent 3,293,407. In this figure, 1 is a ferromagnetic pipe, 2 is an insulated conductor line which enters the ferromagnetic pipe from one end 3 and is connected to the other end 4 after passing therethrough, 5 is a conductor line connected to the above-mentioned one end 3 of the ferromagnetic pipe. The other ends of the above-mentioned conductor lines 2 and 5 are connected to two terminals of an A.C. source 6. When an A.C. of a suitable frequency is passed through the circuit thus formed, the A.C. flowing through the pipe 1 is concentrated in a limited inside surface region (skin region) of the pipe 1 due to skin effect, generating a Joule's heat corresponding to the electric resistance of the above-mentioned skin region and substantially no electric potential appears on the outside surface of the pipes 1 and 1'.

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Figure 2 shows a construction of another heat generating pipe disclosed in U.S. application Ser. No. 627,086. In this figure, 1 and 1' are two ferromagnetic pipes. An insulated conductor line 2 is passed through the pipes 1 and 1' successively as shown in Figure 2 and both the ends of it are connected to different terminals of an A.C. source 6. The one end 3 and 3' of the ferromagnetic pipes 1 and 1' and the other ends 4 and 4' of the same pipes 1 and 1' are connected, respectively, with conductor lines 7 and 7' (e.g., electric wire). When an A.C. of a suitable frequency is passed through the conductor 2, an A.C. is induced in the ferromagnetic pipes 1 and 1', and flows through the circuit formed by the ferromagnetic pipes 1 and 1' and the conductor lines 7 and 7'. When the impedances of the conductor lines 7 and 7' are arranged to be substantially zero (which can be realized by shortening the conductor lines 7 and 7' by placing the ends of the pipes 3, 3' and 4, 4' respectively as close as possible, and using the conductor lines 7 and 7' of which the electric resistance is as low as possible), the current flowing through these pipes is concentrated in a limited inside surface region (skin region) of the pipes 1 and 1' due to skin effect, generating a Joule's heat corresponding to the electric resistance of the said skin region, and substantially no electric potential appears on the outside surface of the ferromagnetic pipes 1 and 1'.

In the above-mentioned two types of heat generating pipe, the depth or thickness S of the inside surface region of the ferromagnetic pipe in which the A.C. flows, is expressed by the following equation:

$$S = 5030\sqrt{\rho/\mu f} \qquad (1)$$

wherein ρ is the resistivity of ferromagnetic material constructing the pipe (Ω cm), μ is the permeability of the same material and f is the frequency of A.C. (Hz).

If there are relations expressed by formulae

$$t > 2s$$
$$d \gg s \qquad (2)$$
$$l \gg s$$

among the thickness t (cm) of the ferromagnetic pipe used, the inside diameter d (cm) of the pipe, the length l (cm) of the pipe and the depth or thickness s mentioned above, substantially no electric potential appears on the outside surface of the ferromagnetic pipes. Even if two arbitrary points of the surface of these ferromagnetic pipes are connected by a conductor line 8 as in Figure 1 and 2, no current flows in this conductor. Further a substance can be directly contacted with the surface of such ferromagnetic pipes, without any leakage of current from the ferromagnetic pipes. Accordingly, when the heat-generating pipe of this kind is used to heat a substance, it is possible to contact the substance.

If a depth s of a surface skin in the equation (1) is to be illustrated by a concrete example, it is only 0.1 cm in case where a commercial steel pipe is used as a ferromagnetic pipe and the frequency of a current supplied to a heat-generating pipe is 50 or 60 Hz. Accordingly, a steel pipe having a thickness of more than 0.2 cm can be used as the ferromagnetic pipe of a heat-generating pipe of this kind and there is no need of special precaution to the material of heat-generating pipes and current to be supplied.

Although the heat-generating pipes having constructions shown in Figures 1 and 2 are those applied to single phase circuits, the application of these heat-generating pipes to three phase circuits will be easy for a person having an ordinary skill in the art.

The amount of heat generated (W watt) per cm of the above-mentioned heat-generating pipe can be calculated as follows:

(a) The amount of heat generated in the ferromagnetic pipe (W_1 watt); the resistance R_1 (Ohm/cm) of a ferromagnetic pipe will be

approximately expressed from the equation (1) by the equation of

$$R_1 \doteqdot \frac{\rho}{\pi ds} = \frac{\sqrt{\rho\mu f}}{5,030} \qquad (3)$$

If the amount of current flowing is i ampere, the amount of heat will be expressed by the equation of

$$W_1 = i^2R_1 \doteqdot \frac{i^2\sqrt{\rho\mu f}}{5,030} \qquad (4)$$

(B) The amount of heat generated in the insulated conductor line (W_2 watt).

If the resistance per cm of a conductor line is R_2 (Ohm/cm), the amount of heat will be expressed by

$$W_2 = i^2R_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The heat generated in the insulated conductor line is conducted mainly by a medium between the conductor line and the ferromagnetic pipe. Such a medium is usually air but a better heat conductor such as water, oils and other liquid medium may be used. The use of such a liquid medium renders the allowable current of the conductor line about three times as large as that of gaseous medium, e.g., air. Thence the use of liquid medium is economical particularly in case of high capacity heat-generating pipe.

Thus the amount of heat generated per cm of this kind of heat generating pipe (W watt) is the sum of the amounts of heat generation expressed by the above mentioned equations (4) and (5).

$$W = W_1 + W_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

and approximately $W \doteqdot \frac{i^2\sqrt{\rho\mu f}}{5,030} + i^2R_2 \quad \ldots. \quad (7)$

The above-mentioned heat-generating pipe utilizing skin effect current can be made to extend as long as several kilometers by supplying electricity from only one point if the electric potential of an electricity source which supplies electricity to it is elevated. This is one of the notable advantages of the heat-generating pipe of this kind. When one heat-generating pipe of such a long length

is installed with bendings in order to use it in the heating of surfaces of constructions such as floors of buildings, wall surfaces or road surfaces, it is possible to some extent to change locally the amount of heat to be supplied to a to-be-heated surface by adjusting the density of heat-generating pipes installed per unit area of to-be-heated surface. On the contrary, it is impossible to adjust locally the amount of heat to be supplied, as it is, in the temperature maintenance and heating of such a linear construction as a pipe line.

In general, when a long pipe line is installed, the environment of installed pipe lines is not uniform. There will be changes in whether sunshine is large or small, whether it is above or under the ground or whether it is in water or not and heat loss from the pipe line varies depending upon each environment. Further there may be a case where a part of the transporting material is separated into a different stream line or a different stream line is introduced in the course of a pipe line, causing the local change of the amount of flow and hence the local change of the amount of heat to be supplied. When a pipe line is designed based upon the maximum amount of heat to be supplied, the amount of heat generation in a part where lesser amount of heat is required becomes excessive, which is not desirable because transporting fluid is overheated. It is possible to avoid such excessive heat generation by dividing a heat-generating pipe into various sections and supplying respectively, electric potentials suitable to each section. However, such a method is not preferable because it makes the unified control of a heat-generating pipe impossible and diminishes the above-mentioned notable advantage of the heat-generating pipe of this kind.

Accordingly, it is an object of the present invention to provide a method for solving the problem relating to the drawback of the heat-generating pipe of this kind.

Such an object can be attained by the method of the

present invention which is characterized by changing one or more factors of those consisting of cross sectional area of conductor line, resistivity of the same, resistivity of ferromagnetic pipe, permeability of the same and inside diameter of the same to locally control heat quantity generated in a heat-generating pipe utilizing skin effect current and consisting of a ferromagnetic pipe and an insulated conductor line installed therethrough wherein an A.C. flows through concentratedly only in the inner skin region thereof, and the strength and frequency of electric current flowing through the insulated conductor line and the heat-generating pipe are constant.

As expressed approximately in the above-mentioned equation (6), the amount of heat generation per unit length of this kind of heat-generating pipe is the sum of the heat generated in the inside skin region of the ferromagnetic pipe, $W_1 \doteqdot \frac{i^2\sqrt{\rho\mu f}}{5{,}030\pi d}$ and that generated in the insulated conductor line, $W_2 = i^2R_2$. Among the factors having influence on the above-mentioned heat generation, current (i) and frequency (f) of A.C. are constant in each part of the heat-generating pipe and cannot be changed, but (1) resistivity (ρ) and (2) permeability (μ) of a ferromagnetic pipe can be changed by changing the material of the ferromagnetic pipe, (3) diameter of a ferromagnetic pipe can be selected arbitrarily even when the pipe is of the same material and (4) resistivity (R_2) of an insulated conductor line can be varied by arbitrarily selecting a material and/or diameter of the conductor line. In general it is convenient to construct a heat-generating pipe utilizing skin effect current and having a wide range of variation of heat-generating amount per unit length using a steel pipe and a copper wire most easily available in the market and changing the inside diameter of the steel pipe and/or the cross-sectional area of the insulated conductor line.

One embodiment of the present invention can be explained by referring to Figure 3. In this drawing, 9 is a fluid-transporting pipe one portion of which is installed above the ground and

another portion of which is installed underground. 10 shows soil and sand. The portion installed underground requires lesser amount of heat compared with the portion in the air for maintaining the temperature. In some cases, it is possible to minimize the change of the fluid temperature in a transportion pipe even with constant heat supplying per unit length by using, as a lagging layer 11 for the underground portion, a material inferior in the efficiency of keeping warm to the material of the lagging layer for the portion above the ground or by reducing the thickness of insulation layer. However, it is desirable in general to minimize the change of the fluid temperature by minimizing the heat loss as low as possible. Particularly, in a long distance pipe line, the latter is economical and reasonable.

In Figure 3, 1 and 1' are ferromagnetic pipes installed in a transportation pipe 9. At a junction point 12, they are connected by welding. 2 and 2' are conductor lines passing through the ferromagnetic pipes 1, 1'. The one end of the conductor line 2 is connected to one terminal of A.C. source 6 as indicated by a broken line, and the other end of which is connected to a conductor line 2' through the junction point 13, and the conductor line 2' is connected to one end of ferromagnetic pipe 4 after passing through the ferromagnetic pipe 1'. On the other hand, one end 3 ofthe ferromagnetic pipe 1 is connected to the other terminal of A.C. source 6 by a conductor line 5 as indicated by a broken line and thus a heat-generating pipe is constructed. 14 is a connection box attached to the heat-generating pipe. If kinds of insulated conductor lines are changed in one heat-generating pipe as in this example or if a heat-generating pipe is long or has many bends, the connection box is convenient for the construction and management of the heat-generating pipe.

In applying the method of the present invention to a case illustrated in Figure 3, a material having a greater

resistivity and/or permeability than those for the pipe 1' lying in the underground may be used for a ferromagnetic pipe 1 of a heat-generating pipe lying above the ground, or if the same material is used, the diameter of the pipe 1' may be reduced, or the material or cross-sectional area of each insulated conductor line is selected in such a way that the resistance of the line 2 is greater than that of the line 2'.

Since the heat quantity W_2, i.e., i^2R_2 generated in an insulated conductor line is exceedingly small compared with the heat quantity W_1 generated in the ferromagnetic pipe, among the total heat quantity W of this kind of heat-generating pipe which can be expressed by a formula (6) or (7), it is not so effective to make changes in the insulated conductor line in order to change the heat generation of the heat-generating pipe.

Commercial steel pipes are useful for the ferromagnetic pipes of the heat-generating pipe of this kind, because it is inexpensive and available from market in various sizes. Accordingly, it is most convenient and effective to use steel pipes in the practice of the present invention and change locally their inside diameter according to the demand of local control of heat generation. For example, in Figure 3, such an arrangement will be sufficient that a steel pipe 1 having a relatively small inside diameter is used in order to increase heat generation based upon the equation 4 in the heating of the portion lying above the ground where the heat loss is relatively large and a steel pipe 1' having a greater inside diameter than that of 1 is used as a heating pipe for the portion lying in the underground. The selection of the diameter of ferromagnetic pipe can be made easily by the calculation based upon a required temperature and heat loss using an equation (3).

The foregoing description is offered to illustrate a preferred embodiment of the present invention and not to limit the material of ferromagnetic pipe constituting a heat-generating pipe

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only to a steel pipe in the method of the present invention.

Further, the foregoing description is almost directed to the case of application in pipe lines, but the method of the present invention can also be applied widely and effectively to the heating for temperature maintenance, prevention of freezing or melting of snow for walls of constructions, floors, roofs, road surfaces, runways for aircraft, surface grounds of railways or tracks, bridges and power-transmission lines, and to the heating or temperature maintenance of tanks wherein temperature reduction is undesirable.

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THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. In the known type of heat generating apparatus comprising a length of ferromagnetic pipe, a first length of an electrical conductor line disposed within said ferromagnetic pipe but insulated therefrom, and electrical and power connections such that upon the passage of alternating voltage through said first length of electrical conductor line there is a concentrated flow of current along the inner skin of the ferromagnetic pipe to thereby generate heat in said ferromagnetic pipe, the improvement which comprises:

(a) said ferromagnetic pipe being composed of at least two segments of differing heat generating capacity,

(b) the heat generating ability of each of said segments of pipe being governed by primary heat generating factors which include

(1) the cross-sectional area of the conductor line,

(2) the resistivity of the conductor line,

(3) the resistivity of the ferromagnetic pipe,

(4) the permeability of the ferromagnetic pipe, and

(5) the inside diameter of the ferromagnetic pipe,

(c) at least one of the segments of said ferromagnetic pipe being constructed so that it has at least one of the aforesaid heat generating factors which is different from the corresponding heat generating factor of another segment of the ferromagnetic pipe.

2. In the known type of heat generating apparatus as claimed in claim 1 wherein said ferromagnetic pipe has at least one segment wherein the cross-sectional area of the conductor line passing therethrough differs from that of at least one other segment of the ferromagnetic pipe.

3. In the known type of heat generating apparatus

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as claimed in claim 1 wherein said ferromagnetic pipe has at least one segment wherein the resistivity of the conductor line passing therethrough differs from that of at least one other segment of the ferromagnetic pipe.

4. In the known type of heat generating apparatus as claimed in claim 1 wherein said ferromagnetic pipe has at least one segment wherein the resistivity of the ferromagnetic pipe differs from that of at least one other segment of ferromagnetic pipe.

5. In the known type of heat generating apparatus as claimed in claim 1 wherein said ferromagnetic pipe has at least one segment wherein the permeability of the ferromagnetic pipe differs from that of at least one other segment of the ferromagnetic pipe.

6. In the known type of heat generating apparatus as claimed in claim 1 wherein said ferromagnetic pipe has at least one segment wherein the inside diameter of the ferromagnetic pipe differs from that of at least one other segment of the ferromagnetic pipe.

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Fig. 1.

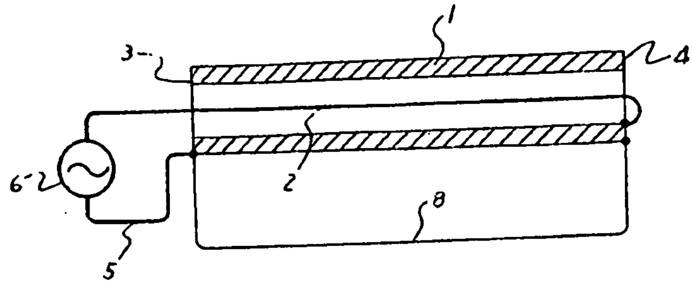


Fig. 2.

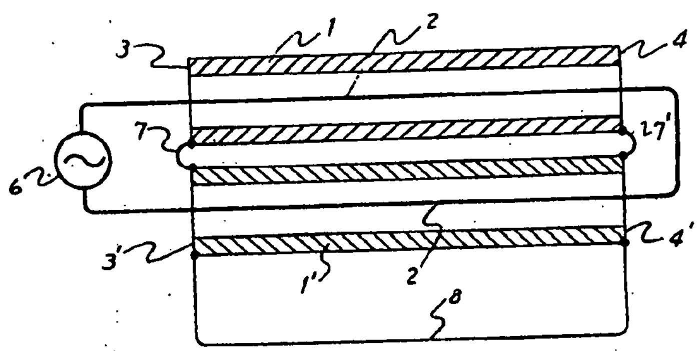
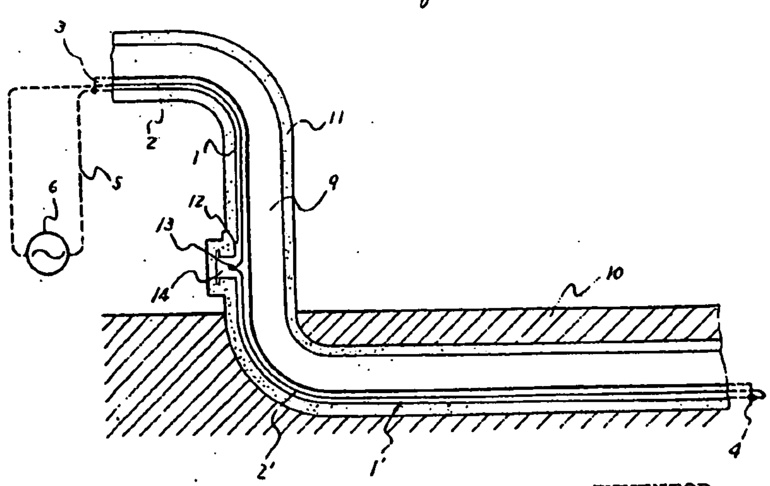


Fig. 3.



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